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ABSTRACT

This paper was originally developed for the workshop, the Secondary Science Education for Development, and examines the factors shaping educational policy in developing nations. Four sections include: (1) a discussion of two different approaches to the formation of science education policy; (2) an elaboration of the dimensions of the policy context for science education in developing countries; (3) the examination of specific issues in depth; and (4) concluding remarks. (Contains 18 references.) (YDS)

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SECONDARY EDUCATION SERIES

MAPPING SCIENCE EDUCATION POLICY IN DEVELOPING COUNTRIES

Keith M. Lewin

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EDUCATION
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Secondary Education Series

Mapping Science Education Policy in Developing Countries

Keith M Lewin

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Contents

Foreword..... iii

About the Author..... v

Introduction..... 1

Two Approaches to Policy Formation..... 1

The Policy Context..... 5

Participation..... 5

Financial Constraints..... 8

Supply and Demand in Education and the Labor Market..... 9

Different Needs for Different Groups..... 11

Policy and Planning Issues..... 13

Specialisation and Special Science Schools..... 13

Curriculum Issues..... 16

Learning and Teaching Materials..... 19

Practical Science, Laboratories and Equipment..... 20

Selection and Assessment..... 23

The Training of Science Teachers..... 28

Information and Communication Technologies and Science Education..... 32

Concluding Remarks..... 35

References..... 38

Foreword

Welcome to the Secondary Education Series of the Human Development Network, Education Group at the World Bank.

The World Bank has been assisting developing countries in their efforts to reform their secondary education systems for more than 35 years. During this period, the context and imperatives for education reform have changed considerably due to various factors such as globalization of the world economy and the impact of new technologies. This new environment requires rethinking the traditional way of providing secondary education and training systems and both industrializing and industrialized countries are grappling how best to prepare their youth to become productive workforce as well as responsible citizens. Thus, this series will address a wide range of topics within secondary education that reflect the challenges that we are facing now.

This paper, "Mapping Science Education Policies in Developing Countries", is the second publication in the Secondary Education Series. Along with the third publication in this series, "Linking Science Education to Labour Markets: Issues and Strategies", this paper was originally prepared for the workshop, the Secondary Science Education for Development (http://www1.worldbank.org/education/scied/Training/training.htm), which was organized by the Education Group in April 2000. The workshop aimed to explore some of the issues involved in science education reform within a larger context of social and economic development. We hope these two new volumes will provide with opportunities to further explore these issues with our clients. We welcome your comments.

Finally, this paper was developed based on the findings of the previous work that Keith Lewin co-authored with François Caillod and Gabriele Gottelmann-Duret, *Science Education and Development: Planning and Policy Issues at Secondary Level* (Paris: Pergamon/UNESCO, 1997).

World Bank
Human Development Network
Education Group
August 2000

About the Author

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Introduction

This paper maps out the factors that shape science policy in developing countries. It is organised in four sections. First, two different approaches to the formation of science education policy are discussed. Second, the dimensions of the policy context for science education in developing countries are elaborated. These include questions related to participation, financial constraints, the supply and demand for science education, and the different needs for different groups. Third, specific issues are discussed selectively in more depth. These include the debate on specialisation and special science schools, the structure and organisation of the science curriculum, the provision of learning materials, the role of practical activity, problems of assessment and selection, and patterns of science teacher education. The last section provides some concluding remarks.

Two Approaches to Policy Formation

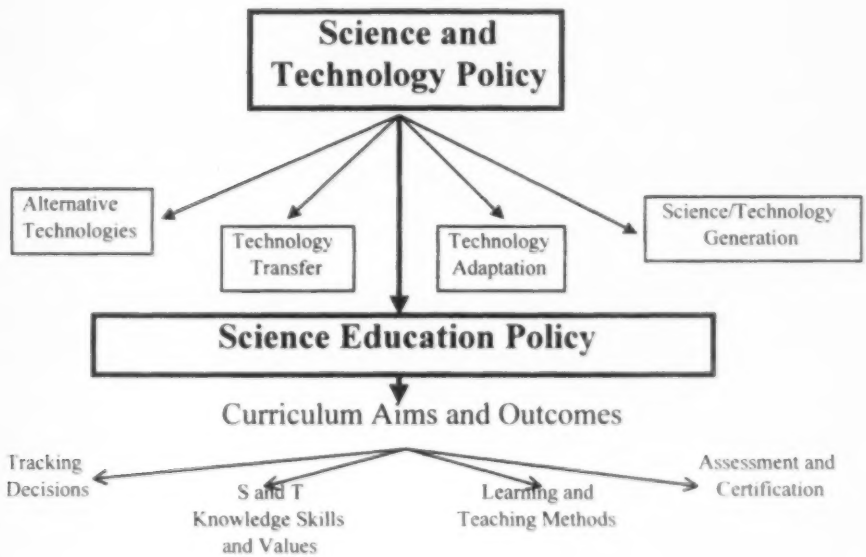
Science education policy can be developed in two different ways. The approach most familiar to planners and policy makers is from the top down and starts with the identification national goals which can be converted into policy for different sub sectors. Most developing country national plans since the 1960s have contained commitments to invest in science and technology in the belief that this will enhance economic development. Recently it has become more common to argue that general statements of commitment are not enough, and that specific policy on science and technology is needed which is associated with particular economic development strategies. If such a policy can be articulated then the logic of this approach leads to decisions about the kinds of science and technology education and training that should be promoted.

Four overlapping national needs related to science and technology are often identified. These are to generate new technology (usually thought to be science based); to adapt technology developed elsewhere to suit local market conditions and factor endowments; to transfer technology essentially unchanged but relocated, and to devise different technologies appropriate to context which may not already exist. The nature of these needs raises fundamental issues about the development process beyond the scope of this short paper. A modest elaboration is justified since it is perspectives on which of these needs are dominant which are likely to shape science education policy and practice. Orthodox views of science education tend to stress the importance of discovery, invention and understandings of the natural world over application, improvement of already existing technologies, and the development of scientific knowledge related to the needs of the poor and marginalised. Role models are those of the great scientists who have shaped modern science. Much school science replicates their experiments. The central point is that the kinds of science education and training that might prepare young people to generate new technologies, invent new products, and discover fundamental scientific truths may well not be the same as that best suited to needs to adapt the application of science and technology to new contexts. A strategy to promote technology transfer may invite emphasis on a secure understanding of basic concepts and their application, systematic approaches to the incremental improvement of mature technologies, and the development of diagnostic and maintenance skills, rather than on those of curiosity driven creative exploration. If the development of alternative technologies really were to be adopted as a priority, then traditional science education and training would have to be substantially re-orientated. This might include a

stress on the social context of application, the utilisation of old as well as new technologies adapted to suit needs, and more emphasis on sustainable lifestyles sympathetic to the environment.

In principle, if it is possible to define a development strategy related to science and technology needs, then this can be used as a basis to identify where the emphasis in science education should lie. This way of looking at science education policy does try to derive its rationale from national development needs. It leads to the identification of curriculum aims. Choices then have to be made on tracking (how many students should study how much science in which types of institution); science and technology knowledge, skills and values in the curriculum (valued outcomes); learning and teaching methods; and assessment and certification. Figure 1 illustrates a top down approach.

Figure 1. Science Education Policy from the Top Down



There are many criticisms of top down approaches. These include assertions that such policy is unresponsive to the needs of the mass of people and reflects the priorities of governmental and technocratic elites; that problems of participation and achievement have their roots in perceived lack of relevance to individual needs and contexts; and that marginalised groups are often over

looked in the process of defining and implementing policy. Centralised planning, which generates push models for change, has not been consistently successful, though in some cases it appears to have had some impact.

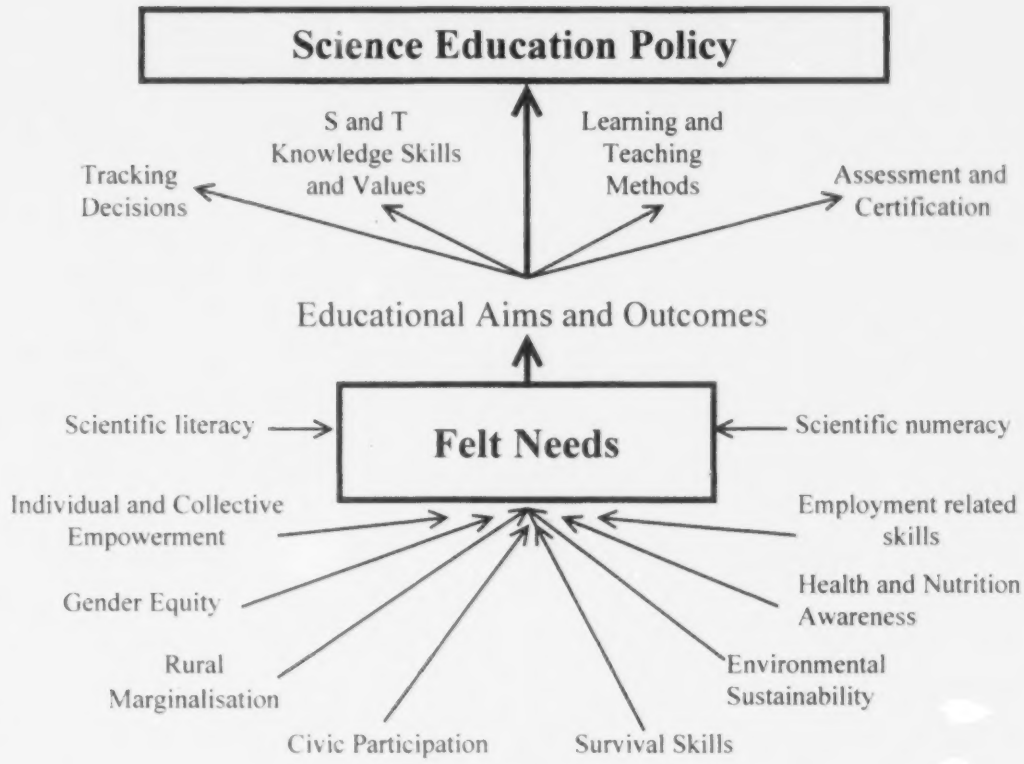
Effective demand has often proved a strong countervailing force as individuals express preferences and make judgements about the attractiveness, quality and relevance of science education programmes.

An alternative view of policy generation starts from individual and social needs rather than a governmental view of priorities for development. It stresses the pull of effective demand. Instead of asking the question what kind of science education policy would be consistent with national development policy designed to lead to economic growth, it explores the needs citizens express and relates these to education and training in science. The general profiling of these needs is not difficult. Their more precise delineation varies according to circumstance, economic development level, and cultural disposition and many other factors specific to context.

This bottom up view of policy development is reactive rather more than it is pro-active. It is grounded more in social demand than in priorities derived from economic development needs. It should result in the specification of educational aims and outcomes that are valued by those who participate or want to participate in science education. If stakeholders needs are recognised in the policy development process it ought to strengthen effective demand for science education of kinds relevant to meeting those perceived needs.

It is easy to exaggerate how easy it might be to adopt bottom up strategies. There are many potential pitfalls. Individual and group interests can conflict with no obvious resolution. So can those of different interest groups. An accumulation of felt needs may lack coherence and integrity if it has not been mediated in ways that create feasible educational aims and outcomes. And though the approach can in principle lead to a consensus about tracking, curriculum, learning and teaching methods and assessment and certification, it might not. Science education policy as emergent from the bottom up does respond to some of the critiques of top down policy that many felt needs are ignored, and that participation suffers if relevance is not perceived. It cannot alone guarantee that what emerges is an efficient way to meet national needs for human resource development in science and technology that tend to require long lead times and consistent investment in institutions, curricula and teachers. Figure 2 illustrates a bottom up approach.

Figure 2. Science Education Policy from the Bottom Up



There is no simple resolution of the basic differences between the top down and bottom up approaches. It is tempting to argue that a compromise is possible. There should be a way of recognising that both have merit. National needs do have a status that is different to that of the felt needs of individuals. It is the job of democratic governments to reach accommodations in the collective interest and to identify priorities which are believed to be in the best interests of the majority, whilst protecting the position of minorities. However this is achieved, policy will only be converted into learning and teaching realities if what is proposed does enjoy some level of consensus and is seen to have benefits to individuals as well as society more generally.

One way forward is to adopt a consultative methods coupled with policy analysis of national priorities. It is possible for governments to listen to stakeholders, whilst also allowing analysis of development needs to shape policy in ways which recognise, but are not necessarily led by, the demands generated by felt needs of individuals and groups. This is more likely to be feasible in those countries where civil society is well developed, professional organisations related to science and technology established, and infrastructure is sufficient to support planned implementation of whatever may be decided. Where policy is little more than the arbitrary exercise of power, professional advice weak or ineffectual, and consultative structures fragile or non-existent it is of course not an option.

This section has outlined two essentially different approaches to policy formation. Their description draws attention to some of their fundamental differences. In practice one or other may be dominant depending on the issue and the approach adopted. Some issues – constraints arising from low enrolments, restricted finance, and the characteristics of demand may seem essentially top down in character. They can be viewed bottom up providing it is remembered that whatever emerges from felt needs in terms of priorities has to be addressed in ways which recognise what exists and has to be expressed in terms of feasible choices. Similarly decisions on specialisation, the organisation of the science curriculum, learning materials, practical activity, problems of assessment and selection, and patterns of science teacher education can also be viewed either as top down planning problems or as ones which should respond to the aspirations of the various groups of stakeholders.

We now turn to explore the policy context more explicitly in terms of some of its most important features in developing countries.

The Policy Context

Participation

There are a number of factors that shape the policy context for science education in developing countries. Four are considered. The first identifies questions related to participation, the second notes the importance of financial constraints, the third explores the dimensions of supply and demand for science education, and the fourth draws attention to different needs for different groups.

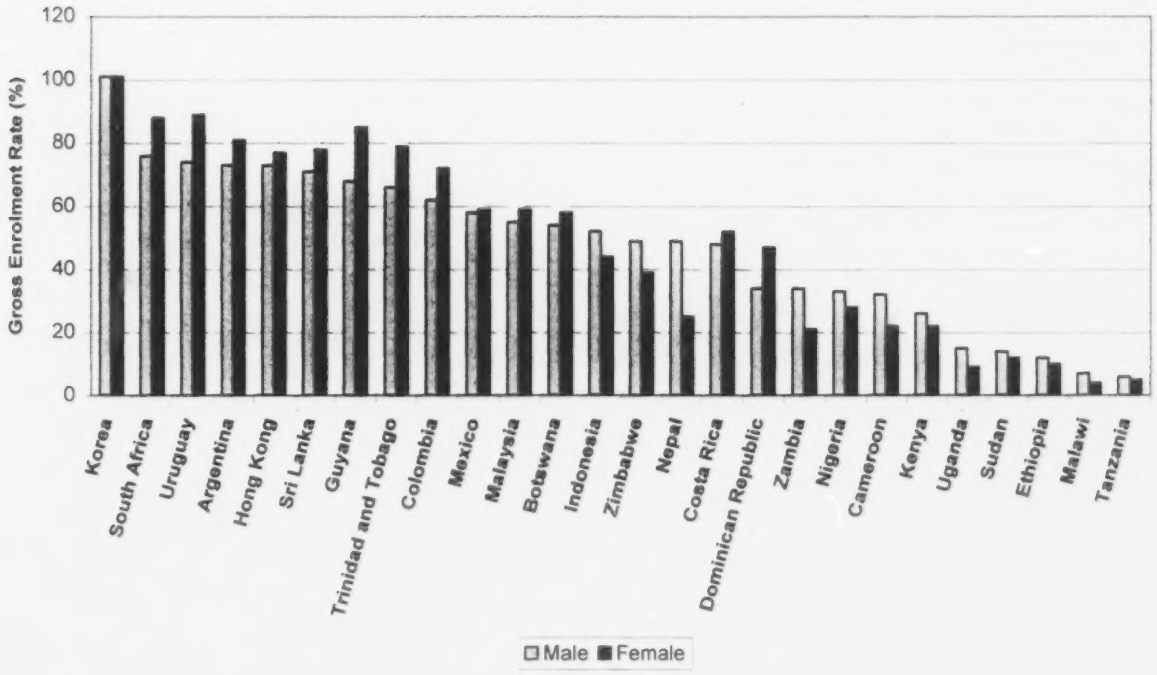
The opportunity to learn science is determined by overall participation rates, and by the organisation of the curriculum and school system that makes it possible to follow science course of a general or specialised kind. Key indicators of participation in science education are overall enrolment rates at secondary, differences in enrolment between groups (rich/poor, males /females, urban/rural etc.) and the proportions specialising in science at different levels.

Data on gross enrolment rates at secondary is widely available. It shows large disparities in rates between developing countries. In some less than 5% of an age group succeed in completing secondary schooling successfully. The majority of the countries with secondary school enrolment rates below 40% are in Africa (Lewin and Caillods 2000). Figure 3 shows enrolment rates at secondary for a number of different countries. Middle income developing countries have the great majority of children enrolled in the secondary grades. In contrast some of the poorest countries have gross enrolment rates of between 5% and 10%. Levels of gross enrolment at secondary in most developing countries suggest that less than half the school age population experience secondary science to any depth. The gross enrolment rate places a maximum on the numbers who have the opportunity to study science at secondary level. In many cases the organisation of the curriculum and the fact that science is not always a compulsory subject means that significantly smaller proportions take science than those enrolled.

Figure 3 also illustrates that in many of the higher income developing countries and some of the low income countries, female enrolment is greater than that for males. If female

participation in science is relatively low in these cases it is more likely to be the result of school level policy on curriculum, specialisation and option choice, than because of overall enrolment differences. Data on the participation rates of other groups (the poor, rural students, particular ethnic groups) is generally only available at a country level and is often unreliable. These groups may be most marginalised from participation in science education. The reasons will be very varied. Nevertheless any analysis of policy context at a country level must concern itself with taking a view on the structure of participation as well as its overall level.

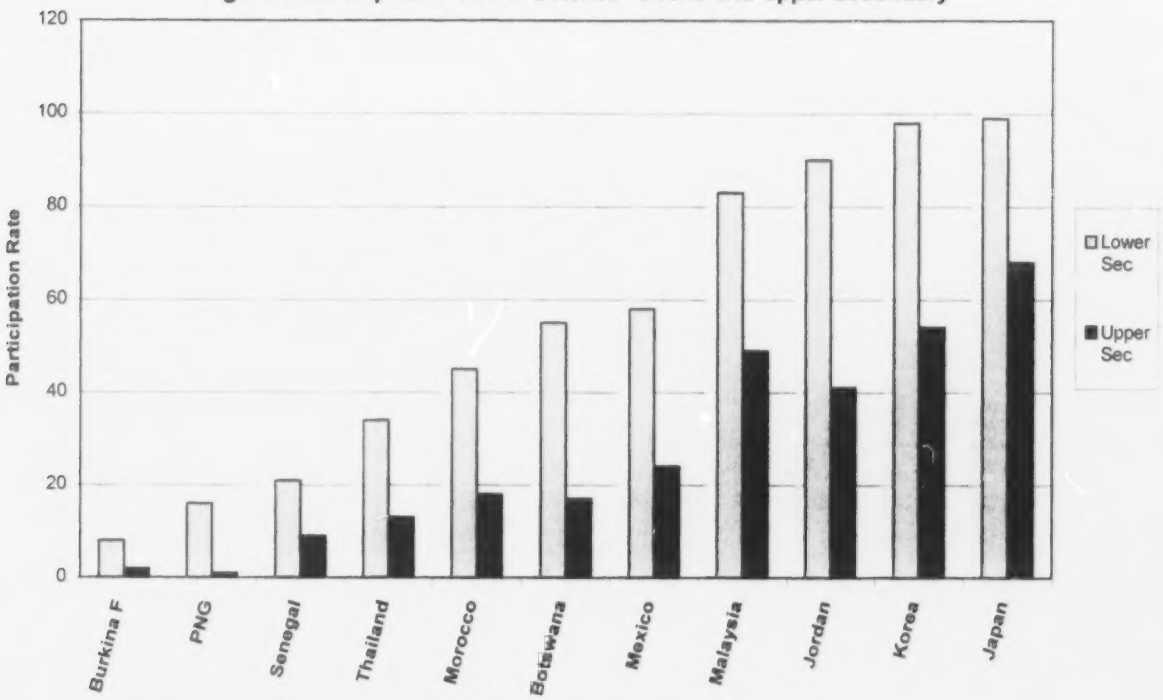
Figure 3. Male and Female Gross Enrolment Rates at Secondary



Source UNESCO Statistical Database 1998

The proportions of those who participate in secondary school who specialise in science are difficult to determine. Comparable cross-national statistics are not available. The data in Figure 4 suggest that the range can be between no more than about 5% to 100% at lower secondary level and from 2% or 3% to over 60% at upper secondary level. Science at secondary level is provided in different ways, most obviously through a general or integrated common course for all students, or through specialised subject disciplines (e.g. physics, chemistry and biology). Participation rates at upper secondary are typically between 50% and 30% of those at lower secondary, as a result of attrition and policy on streaming and option choices.

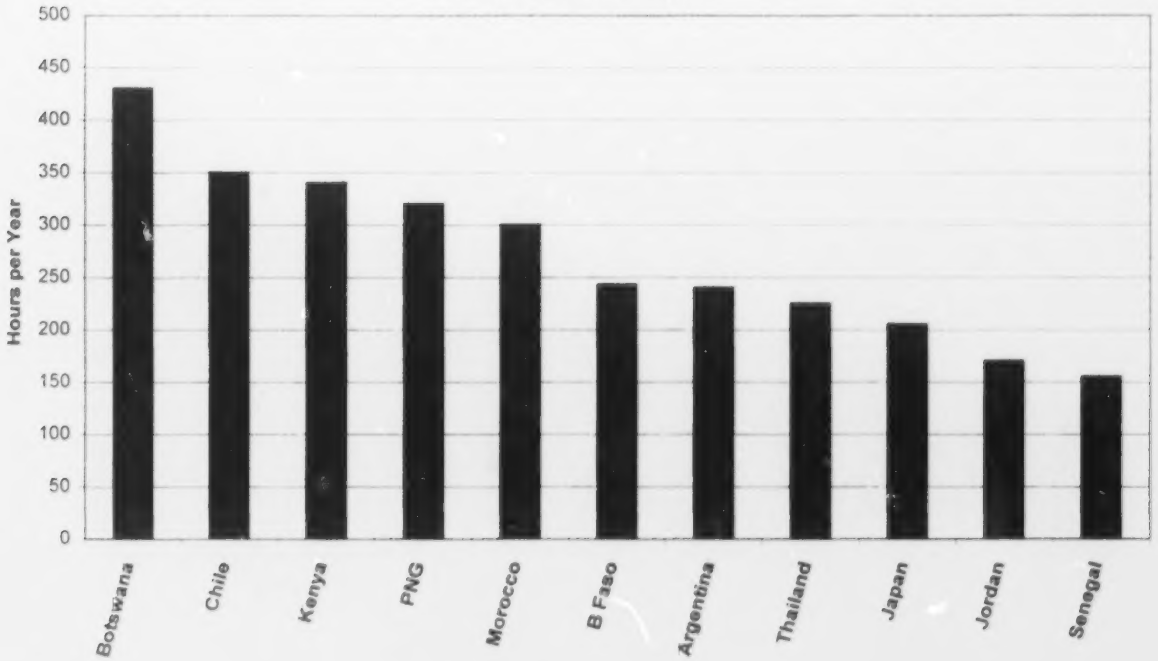
Figure 4. Participation Rate in Science - Lower and Upper Secondary



Source: Caillods, Gottelman-Duret and Lewin 1997

These participation rates have to be interpreted in the light of the amount of time allocated to science in the curriculum. Figure 5 shows how widely this varies across countries at lower secondary level where in most cases all students take the same courses. At upper secondary the range is even wider. Most systems offer a range of pathways and time allocations that are impossible to summarise simply. Some allocate more than 600 hours to science and mathematics over the school year at this level.

Figure 5. Number of Hours for Science and Mathematics Lower Secondary



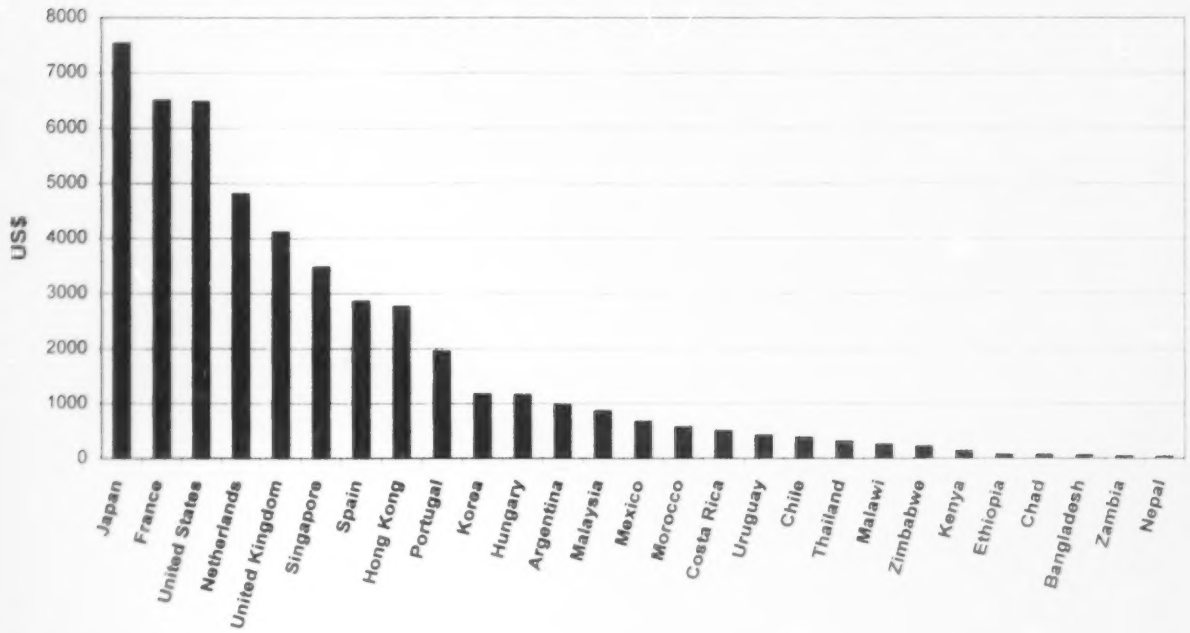
Source: Cailloids, Gottelman Duret Lewin 1997

Financial Constraints

The financial constraints on investment in science education determine the range of options that exist to provide learning materials, physical infrastructure and equipment, and consumable materials. Science education budgets are rarely identified separately. Detailed studies indicate that science education does often receive greater amounts of non-salary recurrent finance than other subject areas. In most systems salary costs are similar for science and other subjects. In some cases science teachers are better rewarded than others, as incentives are thought to be needed to retain their services. The resources allocated to secondary schools provide some indication of the constraints that exist in different countries. Figure 6 shows the amount spent per secondary student in different countries. The richest countries allocate more than $5000 per child per year; the poorest less than $50. Moreover most of these allocations are to teachers' salaries. This is disproportionately so in the poorest developing countries. If even 10% of per child expenditure is retained for non-salary expenditure and of this 20% is allocated to science education then the amounts available per year in the poorest countries can be as low as $1 per child. The policy question this raises is obvious. What can be provided has to be tailored to sustainable levels of resourcing. These are very low in poor developing countries. They can be enhanced if selection and specialisation are favoured which allow the concentration of investment in a limited number of schools. The price is that what can be provided to the general school population will be less than it otherwise would be. The benefit is that those selected to

specialise in science may have access to facilities that are recognisably similar to those in richer countries.

Figure 6. Amount Spent per Secondary Student in US$



Source: UNESCO Statistical Database 1998

Supply and Demand in Education and the Labour Market.

The third set of contextual issues is concerned with supply and demand. The characteristics of these provide some guide to policy development. Data on participation, selection ratios, promotion rates, the output of science qualified students at different levels, and employment can provide the basis for judgements of whether there are bottlenecks in the flow of science students that need to be addressed. The basic questions revolve around an assessment of whether participation in science education is supply or demand constrained at different levels, and whether there is a case to act to increase supply or demand related to national development strategies on human resource development. On the demand side there may be a higher or lower demand from students for places in education and training at secondary and tertiary level. Labour market signals will also indicate whether the current output of those qualified in science matches demand from employers in the public and private sectors. On the supply side enough places may be available to meet demand in education and training institutions, or there may be shortages that constrain participation. A simple matrix makes the point (Table 1).

Table 1. Supply of and Demand for Science Education

Supply	Demand	Comment
Schools		
High	High	Improve quality; differentiate tracks and curricula; balance output with demand from higher education
High	Low	Improve demand through public awareness; provide incentives; encourage marginalised groups; improve links to labour market
Low	High	Invest in teaching facilities; train more science teachers; include science in core curriculum
Low	Low	Consider extending access and invest in teaching facilities; understand why demand is low; improve links to labour market
Higher Ed		
High	High	Improve quality; differentiate tracks and curricula; stress application; control costs
High	Low	Improve demand through public awareness; provide incentives; encourage marginalised groups; invest in learning support; check labour market relevance of curricula
Low	High	Increase supply; invest in quality and participation in schools; develop access courses; check labour market relevance of curricula
Low	Low	Consider development strategy in relation to S and T HRD; provide incentives if low demand leads to under supply into labour market
Labour Mkt		
High	High	Improve quality and links between science education output and labour market placement; differentiate curricula
High	Low	Possible over supply; adjust investment in science education downward and/or re orientate tracking and curricula towards areas of high demand; invest in more applied programmes if in demand
Low	High	Invest in science and technology education and training facilities; provide incentives to study S and T; adjust curricula
Low	Low	Consider development strategy in relation to S and T HRD; invest to improve supply demand if strategy needs greater output of S and T HRD.

Source: Derived from Cailloids, Gottelman-Duret and Lewin 1997

The matrix gives some indication of possible conclusions that might be reached from this kind of analysis. These are illustrative rather than definitive. Evidently there are circumstances in which demand for science education places may be high, but supply should not necessarily be increased. For example, this would include situations where labour market signals suggest that greater output will not be absorbed productively, or where quality is so low as to suggest that improving attainment is a prior consideration to expanding access. Where supply is high but demand low, it does not necessarily follow that supply should be reduced. The judgement depends in part on the reasons why demand is low and whether future human resource needs suggest it will rise. Demand may also be low because of the perceived irrelevance of the science education curriculum to employment. It is also possible that demand may be low because of rigidities amongst students in terms of the kinds of employment they will accept (e.g. single subject science graduates who anticipate careers in research organisations). It then may be that

changes in the science curriculum which place more stress on the applied, and greater awareness of the range of career options open to graduates, should be considered.

If a top down view of policy and planning is taken, then in principle it is the current and future demands of the labour market that should shape investment in science education. If vacancies for science trained graduates and secondary school leavers are common, expatriates are often employed in science and technology based jobs, and employers anticipate needs growing in the future, a greater output is called for from the education and training system. Conversely, if there is much evidence of unemployment amongst science graduates and science school leavers, it may be that there is over supply. Matching supply and demand will always be an imperfect art, not least because of the difficulties of predicting labour force demand more than a short period into the future. It is also true that investment in education and training often works on a different time scale to that of changes in labour force demand. Decisions today designed to increase participation and output through investment in increased institutional capacity are only likely to have an impact on the labour market three to five years hence, by which time patterns may have changed in unanticipated ways. However, despite the difficulties, some attempt on a rolling basis to adjust supply and demand is clearly desirable. Without it scarce resources may be more misdirected than would otherwise be the case.

If a bottom up view of policy and planning is favoured, issues of supply and demand remain. Stakeholder concerns and rights based approaches to the reduction of inequity and marginalisation have to be reconciled with resource constraints at some level. Meeting the needs of particular groups may be detrimental to meeting the needs of other groups. Thus prioritisation has to occur. In poor countries with scarce resources the trade-offs involved need careful consideration. Rapidly expanding access may diminish quality to the extent that few if any students succeed in qualifying for the next level of science education. Affirmative action, quota systems and preferential investment in science education carry with them costs which may have an impact on average levels of achievement, and on the availability of investment for general quality improvement. Part of the resolution of how to respond to needs identified from the bottom up lies in considerations of whether such needs arise because of supply or demand side problems. Groups may be marginalised in participation or achievement as a result of absence of schools which teach science (supply side constraint), or because of cultural preferences to favour other option choices (effective demand constraint). The appropriate response will depend on a diagnosis of the reasons for unmet needs.

Different Needs for Different Groups

Judgements about supply and demand are complicated by the need to recognise that science education caters for several different groups and several different sets of valued outcomes. This is the fourth set of contextual issues. It is important to decide what these are in undertaking policy analysis. Most simply five groups of stakeholders exist. These are those who will become qualified scientists and engineers, those destined to work in sub-professional roles which require or benefit from a grounding in science, the remaining general school population, members of marginalised groups with special needs of one kind or another, and those in the informal sector. We can briefly discuss each in turn.

Historically the needs of the first group have dominated much discussion of science education policy. A concern for graduate level supply and demand for qualified scientists and engineers (QSEs) is understandable and appropriate. Outputs of university graduates are relatively easy to determine, graduate labour markets are fairly clearly defined, and the employment of QSEs tends to be more politically visible than that of science qualified school leavers. It can be noted that some countries have concentrated resources in high level, expensive and ambitious research facilities and learning and teaching science at tertiary level. The pursuit of world class scientific capacity has resulted in some cases in skewed budgetary allocations towards higher education that may be difficult to justify by results. Second, the education of QSEs may have been biased towards the needs of research despite the fact that most graduates are more likely to be employed in areas which apply science rather than explore its leading edges. Third, tertiary science curricula tend to be based on recent developments in the most scientifically advanced countries and international networks of scientific organisations, and external examining and professional associations encourage convergence in forms of science education, training and certification at tertiary level. This may or may not have utility for local labour markets and carries implications for the quality and orientation of science education at school level.

At the sub-professional level the supply of adequate numbers of trained technicians, research assistants, skilled production process workers, and tradesmen with science and technology skills is a widespread problem. In many developing countries the supply is chronically deficient and the quality of performance lacking. There are several planning issues. First, a view is needed about the appropriate ratios of professional to sub-professionals educated in science. There is no golden ratio but the experience of industrially developed countries suggests that between 3 to 6 to 1 or more is common and that lower levels result in under-utilisation of graduates, and qualification escalation unrelated to competence. Second, traditional patterns of technical and vocational education tends towards segmentation and specialisation of skill and are predicated on a model of employment opportunity that reflects such specialisation. But job opportunities in many countries are characterised by their multi rather than mono skilled nature. Self-employment often has this character. In the formal sector many of the most successful industries have moved away from specialised single task job structuring to utilisation of labour in ways that require flexible working practices. Third, there is an unresolved debate about the best methods to support the acquisition of middle level technical skill and competence. The main issue is the extent to which the basis for this can and should be laid in school level science education. This is discussed further below.

The needs of the general school population to acquire basic scientific literacy and numeracy have already been identified. It is generally accepted that a basic education cycle should have this as one of its goals. There are three key planning issues. First, how should the curriculum be organised to achieve this end? If science for all is regarded as a core element of the curriculum then it will cease to be an option to the end of the basic cycle, will be allocated appropriate amounts of curriculum time, and taught by teachers with sufficient understanding of science to achieve desired outcomes. Second, science education intended to provide a secure basis for the citizen to engage with science and technology may differ from that intended to prepare students for the next level of science education. Can both goals be accommodated within a single undifferentiated curriculum? Third, what resources are required to assure scientific

literacy and numeracy of sufficient quality to have an impact on levels of scientific awareness in the general population and capabilities to apply scientific knowledge and thinking skills to everyday problems, and what realistically are available to support mass school science?

Groups marginalised from participation in science differ. Remedies for their inclusion need to be based on an understanding of the reasons for exclusion. Key issues appear to include first, identification of which groups are considered excluded. Impoverishment is an obvious starting point. It may be superordinate to other attributes associated with low participation in science. Second, an adequate diagnosis of the reasons for exclusion is essential. Are these predominantly supply side or demand side, or both? Third, if participation, retention and achievement is to be improved which strategies can be demonstrated to be most effective? There are a range of possibilities which include quota systems, special incentives to study science, and preferential access to specialised science based schools.

Finally, those working in the informal sector may often benefit from basic scientific literacy and numeracy but may fail to have acquired it from the formal school system. Their needs should not be ignored. If these are recognised then it is necessary to consider a number of factors. First, to what extent are such individuals literate and likely to benefit from self-instructional material and feasible support programmes. Second, what kinds of science-based knowledge really are most useful to which groups? Third, what methods of providing access to science based knowledge and skills are feasible for those with informal sector livelihoods?

Policy and Planning Issues

The remainder of this paper identifies a range of issues that preoccupy policy makers for science education in developing countries. It is necessarily selective. These are the debate on specialisation and special science schools, the structure and organisation of the science curriculum, the provision of learning materials, the role of practical activity, problems of assessment and selection, and patterns of science teacher education.

Specialisation and Special Science Schools

Policy on specialisation in science is critical. Its results determine at what level access to science education becomes selective and curricula are differentiated to meet different needs, and it shapes the flow of students through the system and into the labour market. There are two main reasons for specialisation. First, it is likely to be the most cost-effective way of deploying scarce resources. If there is no realistic prospect of adequately reaching all schools it may be better to provide well-found learning and teaching facilities for a selected minority. Second, some level of specialisation may be the best way of responding to the range of abilities and interests that students manifest. It allows those with most ability to study in depth, permits student preferences for science and other subjects to be expressed, and does not preclude all students from studying some science.

It is an open question as to how early pupils should be given the option of specialising in science. Those who argue in favour of early specialisation note that those who do well in science early also tend to be high achievers in science later (Wallberg 1991). The supposition is that success at a young age provides motivation to continue to achieve, and that mathematical and scientific

skills and attitudes benefit from early development. It should be noted that few studies address the question of what happens to those who are selected out by early specialisation who may have potential that they are unable to realise. Neither do many openly debate how accurately it is possible to identify those who should specialise, especially in those developing countries where expertise in assessment is scarce.

There are arguments against early specialisation in science. There is a compelling case that priority should be given to science for all at the primary and lower secondary levels. In most developing countries these provide the last chance to acquire the rudiments of scientific literacy. Quality basic education must include science-based knowledge and skills. This may be at least as important for some aspects of development (equity, rural income generation) as special provision for the most talented. Quality basic science education is also important because science learning and its outcomes at the subsequent levels depend on the foundations established over the first eight or nine years. Both for those entering the labour market and for those continuing to study an adequate grounding in science is a prerequisite.

It may also be true that early specialisation reinforces differences between groups. Thus, in many countries where secondary science is optional, girls disproportionately tend to choose against science, or concentrate only on the life sciences. One consequence is continued under-representation of girls in science-based courses at higher education level and in the physical sciences. It may be both inequitable and inefficient to allow girls to opt out of science as a result of early specialisation.

Specialisation takes many different forms (see, e.g. Adamu 1992, Sharifah Maimunah and Lewin 1993). In some countries secondary students specialise through enrolment in a science stream; in others students can choose between two or more science streams offering different science and other subjects in different ways. The degree of specialisation is a function of both the number of subjects studied and the amount of time allocated to them, which gives an indication of depth. Where two or three sciences are studied for more than about 25% of curriculum time specialisation is likely to be high. The same time allocation spread across a wider range of science based subjects offers less depth, but still a high general level of specialisation in science. Where time allocations are much smaller - say 15% or less - specialisation in science is likely to be weak. Where science is a popular choice, time in school may be complemented by much time out of formal school in private tuition in science related subjects.

Useful indicators for planners of the degree of specialisation in science are:

(i) the time (in absolute and relative terms) that those specialising in science spend on science and mathematics,
(ii) the degree to which the curriculum for those specialising in science differs from the curriculum for "non science students" (depth and difficulty),
(iii) the number of science subjects/options taken,
(iv) the weighting of science in the examinations giving access to higher education.

One clear policy option related to specialisation is to create special schools with preferential access to resources and especially well qualified staff. Several countries have opted for this approach at different times, albeit in different ways. The case that can be developed in favour of teaching science in special institutions at secondary level is based on the following arguments:

First, good science teaching is expensive and the necessary resources are scarce (competent teachers, well found laboratories, up to date libraries). It is therefore justified to concentrate on providing quality science education to a small minority of the best students in special institutions.

Second, an adequate supply of competent scientists and technologists is needed to fill places in further and higher education. This may be better assured through tracking the best science students into special institutions with boarding facilities etc., rather than through a dilution of effort across the whole school system.

Third, special institutions with special admissions policies may be needed to teach science in order to increase the participation of historically marginalised groups in science and technology based education and employment.

These arguments advanced in favour of special institutions to teach secondary science have to be balanced against difficulties that commonly arise in establishing a separate track through secondary education for science students. These are likely to include:

- the reliability and validity of methods used to select students suitable for special science schools
- the risks of academicising secondary science in elite institutions to the extent that it loses relevance to national development needs
- the possibility that without separate examination arrangements approaches to learning and teaching science will simply mirror those employed in ordinary schools and lack enriching experiences
- the difficulty of assessing what level of additional costs is justified

Each of these potential difficulties warrants a brief discussion. The first implies the need for technically sophisticated selection methods that can be shown to be valid and reliable. The fewer those selected and the greater the costs of their education, the more important it will be to establish confidence in the selection process. The second invites a reminder that no growing economy employs more pure than applied scientists. The need for science qualified school leavers is likely to be skewed in favour of those with a sound basic science education and some applied science skills. There is a risk that the prestige associated with pure science, and the preferences of teachers (a minority of whom have usually been trained as applied scientists), may reinforce each other to emphasise the theoretical at the expense of the practical, the abstract at the expense of application. It is therefore likely to be important to accord at least equal status to technology and applied science in special institutions.

The third difficulty is that learning and teaching in special science schools may not be qualitatively different in orientation and emphasis if it follows common national curricula and prepares students for the common national examinations. It may be that with the best students, creative teachers, and extensive resources, time will be found for the more exploratory, challenging and intellectually demanding activities that can stretch understanding. If special schools are to emphasise learning goals that are different and more extensive than those associated with the teaching of science in ordinary schools assessment practices may need to be

refined, or additional more challenging assessment provided. Finally, it is easy to accept that special science schools need to be more expensive than normal schools, but difficult to decide what an appropriate ratio might be. Staffing ratios may need to be more generous. If the normal pupil teacher ratio is 25:1 should it be allowed to fall to 15:1 or 10:1 or even less? Equipment costs can escalate to high levels comparable with tertiary institutions if every request with a possible justification is met. There will be a point of diminishing returns where higher costs have little effect on science achievement. Expenditure may need to be controlled by those without a stake in expanding school budgets if appropriate levels are to be set.

The evidence on the effectiveness of special science schools is mixed, as might be expected from the variety of forms they take and the systems within which they operate. Various studies suggest that such schools can contribute to a number of outcomes which include:

- An increased supply of science-qualified leavers over and above what might otherwise be the case
- Greater participation in science education by previously under represented groups
- High levels of achievement in science
- Innovative learning and teaching styles for science not found in mainstream schools

However, costs can be high and the potential disadvantages noted above have to be recognised. Choice for or against special science schools and other forms of specialisation is partly a science education policy question, but is inevitably linked to broader questions of selection and specialisation within different school systems.

Curriculum Issues

Science curriculum development in many developing countries has a long history. Systematic attempts at curriculum reform in most date back the 1960s and early 1970s when many national curriculum development centres were established. Several recent trends can be identified (see Lewin 1992, Ware 1999). These include:

- Greater attention to science-for-all programmes, alongside continued emphasis on curricula designed for those who will continue to study science and the development of primary science curricula.
- More integrated/combined/coordinated/modular approaches, especially at lower secondary level, which draw content from the traditional science disciplines and stress scientific skills and cognitive processes above content.
- Attempts to apply the results of educational research, especially on cognition, to curriculum design and special interventions
- Greater concern for applications of science through technology and more emphasis on skills needed to solve real life problems. Introduction of science and society, environmental and health issues into science curricula
- Outcomes-based approaches to curricula and assessment and evaluation

All these have implications for policy, planning and resources. This discussion focuses on two concerns: subject integration and option patterns, and the role of technology in the science curriculum.

Real world problems that relate to development often do not have their understanding in one science discipline. At lower secondary level the commonalties in aims and objectives between the sciences are far greater than the differences, especially where these relate to cognitive skills rather than content. These considerations have accelerated the movement towards integrating lower secondary courses in which science is taught as a whole without divisions into physics, chemistry and biology. This is now very widespread with only a minority of countries continuing to adhere to separate subject teaching at the lower secondary level.

Integrated courses have several varieties. The integration may be based upon concepts, or topics or may be little more than the mixing of traditional themes drawn from different science disciplines. The most obvious benefit of integrating is to allow a focus on science reasoning skills, which are promoted across a range of learning content. Several integrated curricula are well established and apparently successful. However, the implementation of integrated courses can be problematic. The main obstacles seem to include insufficient preparation of teachers and reluctance to work outside traditional disciplinary boundaries; lack of appropriate teaching and learning materials; and low status compared to single subject sciences. In many countries teacher training courses remain un-integrated and separate subject training of science teachers persists. In some cases integrated courses at school level are not taught by one teacher, but subdivided between several subject specialists which would seem to undermine their basic philosophy.

At upper secondary level integration is relatively uncommon, though it remains the case that the separate sciences have many common learning objectives for practical work and cognitive skills. General science courses that group subject matter, rather than integrate it, are often provided to those who do not specialise. These can suffer from a status inferior to separate subject courses. It may be difficult to attract and retain adequately qualified science teachers to teach these curricula. This is problematic if levels of achievement are low and it is the last science that many entering the labour market experience.

The approach to technology in the curriculum raises important policy questions. Some form of technology education is part of secondary curricula in all regions of the world. A common concern is for the development of practical knowledge and capabilities, as opposed to the academic skills associated with conventional science. Traditional technology courses aimed at developing craft skills have been criticised for two major reasons. First, rapid technological change has led to more job mobility and less need for job-specific skills. Flexible specialisation has become more attractive than mono-skill certification. Second, more concern is being expressed for awareness of and control over the technological innovations that shape peoples' lives. Attempts have been made to introduce a critical approach to the study of technology and its applications and to design and implement science, technology and society courses that place technology in its social, political, environmental and moral context.

Central issues to be addressed by planners and policy-makers are:

(i) whether it is essential to provide technology courses as part of the compulsory curriculum at lower (or upper) secondary levels or whether they should be organised at a post-compulsory stage parallel to academic programmes.
(ii) to what extent science curricula which are "technologised" can accommodate the main aims of technology education at any particular level cost effectively.

Treating technology as a separate subject increases the burden on curriculum time if all students are to follow some technology related courses. Space has to be found in what are often already overcrowded timetables. If technology teaching requires special facilities in addition to those needed for the teaching of science, these have to be provided. If these are conventionally conceived their costs may be high. Most countries do not have trained cadres of technology teachers outside those involved in traditional subject areas where the emphasis has often been on craft skills related to single occupations (carpentry, metalwork, typing etc.). It may be difficult to attract staff into higher level technology teaching where flexible skill application and development and design capabilities are stressed along with associated cognitive achievements.

The aims of technology education may not diverge radically from those of science curricula with an emphasis on application, a focus on real world problems, and an orientation towards logical reasoning skills. If this is true then technologising the science curriculum may well be a much more cost effective alternative to introducing technology as a separate subject, especially at lower secondary level. It has the advantage that a basic grounding in science is usually a pre-requisite for purposeful application of technological skill based on analysis rather than intuition. It simplifies the logistics of providing some technological insights for students. And it offers the prospect of providing technological awareness to those who subsequently specialise in academic science. It may also succeed in offering technological learning experiences to more girls for longer than will be the case where technology is taught as a separate subject. At higher levels the balance of the arguments may be different and the importance of specialisation in areas of technology may weigh in favour of provision separated from mainstream science curricula.

Whichever pattern of curriculum organisation is chosen (integrated, single science subjects, core curriculum and electives, technologised science education) consideration must be given to resource demands. Single integrated courses should be cheaper to deliver at equivalent quality since they offer opportunities to simplify textbook production, teacher training, staffing, timetabling, and laboratory provision, and examining and enjoy economies of scale. By implication it is usually preferable to incorporate material from other areas of science (agriculture, health, environment, earth sceince) into one (integrated) or two (life science, physical science) courses than to attempt to teach them separately. The more options there are, the more the costs and logistic complications of provision will escalate. The planners questions are to ask:

- What is the special value of particular options that justifies the additional costs?
- What are the science learning objectives that distinguish science and technology subjects so clearly that separate curricula are needed?
- How best can different learning outcomes for science be achieved for different groups of students at different levels without multiplying needs for specialist facilities and teachers?

Cross country analysis of curricula suggest that:

- the benefits from integrating science into a single subject at lower secondary are considerable and the disadvantages marginal
- science options at upper secondary should not be allowed to proliferate unless convincing cases based on unique and valued learning outcomes can be made
- content should be reduced where possible in favour of more emphasis on systematic attempts to develop higher order cognitive capabilities than recall and content should be selected taking account of material most likely to be relevant to the majority of students studying particular programmes
- enhancing the applied and technological aspects of science curricula may be more cost effective than developing separate course, except at higher levels

Learning and Teaching Materials

There are well established connections between the availability of learning materials and achievement in schools in developing countries. A matrix can be developed that charts the main issues that relate to provision and which form the basis for policy decisions (See Table 2). This has four dimensions. First, judgements have to be made about the quality and relevance of existing material. If these are both low then systematic curriculum development is probably needed. If quality and relevance are judged adequate an emphasis on supporting the effective use of learning material may be more attractive. It is important to make considered judgements that do not assume that curriculum materials are necessarily the reason for unsatisfactory learning and teaching. The developing world contains many examples of curriculum development projects that have had ambitions to change how science is taught which have not succeeded. This suggests that other factors – patterns of assessment, working practices in schools, cultural dispositions towards particular learning and teaching styles – may be at least as important as the quality and relevance of learning and teaching materials in determining how science is taught. The message from experience seems to be to only embark on resource intensive curriculum development only after establishing that it is indeed the quality and relevance of materials that is a central problem.

Second, where quality and relevance is adequate questions of distribution and availability have to be addressed. Systems vary in their ability to provide text material to students (and teachers guides). The full range of approaches exists between wholly private and wholly public systems for production and distribution. All can work effectively. If they do not, then intervention is needed once it is established where the bottlenecks lie. The choice between more and less public or private production and distribution systems is linked closely to the political preferences of different governments. The planner's question is which methods succeed in providing reliable supplies of appropriate materials in cost effective ways?

Third, the range of materials available needs consideration. So also do patterns of use. If the range is narrow scope exists for enrichment, assuming resources are not too scarce. Many possibilities exist including developing connections to internet-based sources of learning material and information. Patterns of use of materials can be very illuminating. There are cases where officially produced curriculum materials in science are considered less useful than those

available from other sources. Where commercial textbook markets have developed, the pattern of sales may provide a strong indication of what kinds of materials are valued by teachers and students. These may or may not be consistent with the official curriculum. In particular they may be highly assessment-orientated and designed to focus on the narrow range of outcomes tested by conventional external examinations. In many countries examination guides containing key facts outsell science textbooks. If this is so then there must be concern that valued curriculum outcomes may not be being encouraged by the assessment system. It may be that these examination-orientated materials define the science curriculum in action more than do materials produced by curriculum development centres.

Fourth, the costs of learning materials may be problematic. Costs need to be at levels that ensure access. What the costs are and how they are made up is a market specific question. This is a complex area since learning materials production has become a global business. Many factors may need considering in reaching decisions that balance costs, availability, quality and relevance. Local production in country may or may not be cheaper, adaptation of existing material may be cost effective given the commonalities that exit between science curricula, frequent changes to curricula impose high costs for new learning material, and the durability of learning material is an important factor in replacement costs. Cost recovery schemes and textbook loan systems can reduce public costs if successfully implemented.

Table 2. Learning and Teaching Materials

Current Situation of Learning and Teaching Materials		Comment
Quality and Relevance	High	Focus on support for effective use of learning materials (e.g. in service and school based programmes)
	Low	Invest in curriculum development
Access to Core Materials	High	Consider enrichment, extending the range, and developing networks (including the use of information technology)
	Low	Improve production and distribution, consider subsidising costs, identify suitable materials available from other sources
Range and Use of Materials	High	Test for coherence and consistency with valued aims and outcomes, develop quality assurance systems, ensure equitable access
	Low	Commission curriculum development, subsidise production, adapt existing additional materials
Costs of Materials	High	Reduce costs through competition, selective subsidy, economies of scale
	Low	Consider improving quality, range and durability

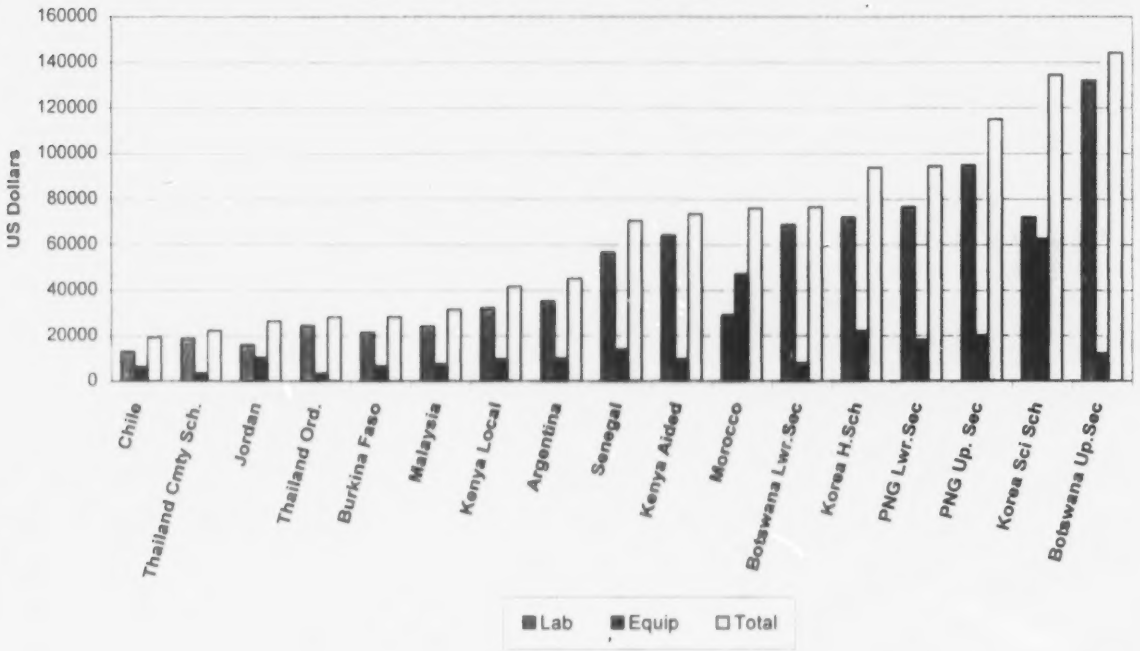
Source: Derived from Cailloids, Gottelman-Duret and Lewin 1997

Practical Science, Laboratories and Equipment

The costs of teaching science are relatively high when compared to other subjects primarily because of the investment that takes place in providing and maintaining practical facilities and the implications these carry for the employment of ancillary staff. In some systems it is also because of the smaller groups size associated with practical subjects. Figure 7 illustrates how

much the costs can be. Despite the many initiatives that have occurred to simplify practical activity in many countries, the teaching of science in a conventional laboratory-based environment remains the normal expectation. This is notwithstanding widespread inability to finance the costs for all except a small minority of students. Where laboratory costs are many multiples of the cost of ordinary classrooms, running costs cannot be sustained, and where laboratories are often used as ordinary classrooms by science teachers, the purpose of high cost provision must be questioned.

Figure 7. Cost of Physics Laboratory



Source: Derived from Cailloids, Gottelman-Duret and Lewin 1997

The main reasons given to justify science practical work in science contain at least four assumptions. These are that practical work is essential to achieve outcomes related to inquiry and (guided) discovery; develop experimental skill; link conceptual learning to concrete experiences and motivate students; and enhance cognitive achievement in science.

All these assumptions can be contested. The first assumes outcomes arising from practical work that cannot be achieved through alternative (and less costly) teaching methods. There is much evidence that the provision of practical facilities is no guarantee that science achievement will be high or that practical work will actually be undertaken with an appropriate frequency or quality. The second anticipates that practical work will be undertaken in ways that allow students the opportunity to develop experimental skills, e.g. those of design of fair tests, interpretation of results, improvement of technique. This may be true but the evidence is that science practical work can become characterised by ritualised replication of standard

experiments undertaken more in a "minds off" rather than "minds on" manner. Third, it may be that concrete experiences are helpful to internalise science concepts. But they are clearly not the only way. Carefully organised demonstrations may be at least as effective and much less costly. Moreover the motivational benefits associated with practical activity may be unevenly distributed amongst students. It cannot be assumed that those without a high motivation to study science will see practical activity as something that is attractive. The opposite is equally plausible. Fourth, strong links between science achievement and the provision and use of practical facilities are difficult to establish. This may be in part because conventional measures of science achievement usually do not emphasise outcomes that can be exclusively associated with practical work and which cannot be acquired through other types of learning.

The role of practical activity in science is often confused with laboratory work. The high status image of laboratory-based science can displace a focus on the thinking strategies and manipulative skills that are the most important outcomes that practical activity can support. Active engagement with problems in the physical world is part of everyday experience and most, if not all, worthwhile thinking skills associated with secondary science can be taught without expensive equipment. Many lower cost alternatives are available and demonstrations, videos and other simulations may be at least as effective, but cheaper than individual or group practical work, in promoting conceptual development.

Our analysis suggests a number of conclusions that planners and policy makers should consider in relation to practical work:

- wherever possible practical work should be designed with costs in mind to make appropriate activities available to relatively poorly resourced schools which have large classes
- the quality and quantity of laboratory-based work should be considered in the light of the learning gains associated with it; it may be that fewer extended but simple experiments, along with simple practical activities, which may not be experimental, are a preferable and more cost effective option than curricula that assume experiments take place virtually every teaching period.
- alternatives to laboratory-based work - thought experiments, demonstrations, simulations, video presentations - should be considered as a substitute for some individual or group class work.

The costs of laboratory provision vary across an enormous range relative to the cost of ordinary classrooms. The differences may be as great as a ratio of 10:1. Where costs are many multiples of normal classroom costs and provision is well short of the number needed for all secondary schools, lower cost alternatives should be considered. The most obvious option is to agree the design of science rooms based on ordinary classrooms that have a selected range of basic facilities adequate to teach non-specialised science through to the end of upper secondary school. This should be possible at no more than double the cost of ordinary classrooms. In summary:

- Laboratory costs should be a relatively small multiple of classroom building costs in all but the most well resourced school systems

- The design of laboratories should, wherever possible, seek to provide a basic range of services that can be sustained and which are appropriate to location, with adequate lighting and ventilation
- Secure storge should be incorporated into the design and safety considerations should be included
- Where space permits furnishing should allow individual and small group work. Provision should allow visible demonstration work
- Science rooms should be considered as an acceptable alternative to laboratories in resource poor systems

The cost of equipment depends on what is specified and where it is produced. National lists of the minimum necessary equipment to teach science should be constructed where these do not already exist, and should be restricted to that which is essential. In summary:

- High cost individual items should be avoided especially if infrequently used. Imported equipment should always be assessed to determine whether local alternatives of adequate quality can be produced.
- Appropriately designed science kits (Ross and Lewin 1992) should be considered as an alternative or as a supplement to the existing equipment base where cost precludes comprehensively equipping all schools. If kits are deployed, advice in their use and arrangements for replenishment should be part of any implementation package.

Selection and Assessment

There are a number of assessment issues that have particular significance for the planning of science education. These are the significance of assessment in science for progression through the school system, the relationships between the curriculum and patterns of assessment, the problems of assessing practical work, and the ways in which assessment information can be used to plan interventions to improve quality and performance. These are discussed below.

First, science is a component of most primary school leaving examinations that give access to secondary school and the promotion examinations that control the transition between lower and upper secondary. Typically it is one of between four to as many as fourteen subjects that are examined. The weighting given to science in different countries at primary and lower secondary selection examinations varies widely between about 5% and 25% of the marks available. In most countries mathematics counts for more than science. The weightings given to science for access to post secondary education are closely related to the subjects of higher study. Science scores may account for half or more of the marks available. In contrast science rarely carries much weight for access to non-science higher level courses.

The rubric of selection subjects and the weighting of science has implications for the numbers of students studying science and the length of time they persist. Some countries place little emphasis on science achievement for access to upper secondary school, others make it compulsory to the end of upper secondary. The acquisition of scientific literacy of a minimal kind would seem to depend on studying science at least to the end of lower secondary and attributing importance to a basic level of achievement.

Second, how secondary science is taught, which topics are emphasised, and what motivation students have to acquire scientific knowledge and skills are all likely to be strongly influenced by the nature of what is assessed. There is an extensive literature on the general effects of assessment on teaching and learning in developing countries, which illustrates the degree to which educational practice may be determined by the choices made in measuring outcomes. There is evidence that many public examinations in science continue to be heavily dependent on items that test the recall of information. This is despite much advocacy of the need to assess higher order cognitive outcomes. Figures 8 and 9 illustrate the results of an analysis of items in papers used for selection to secondary schools in nine African countries. These show that it is still the case that science examining at secondary school entrance level weights recall heavily. Not only that, many items are text based and thus test language capability as well as science knowledge.

Figure 8. Cognitive Demand - 1997 Papers

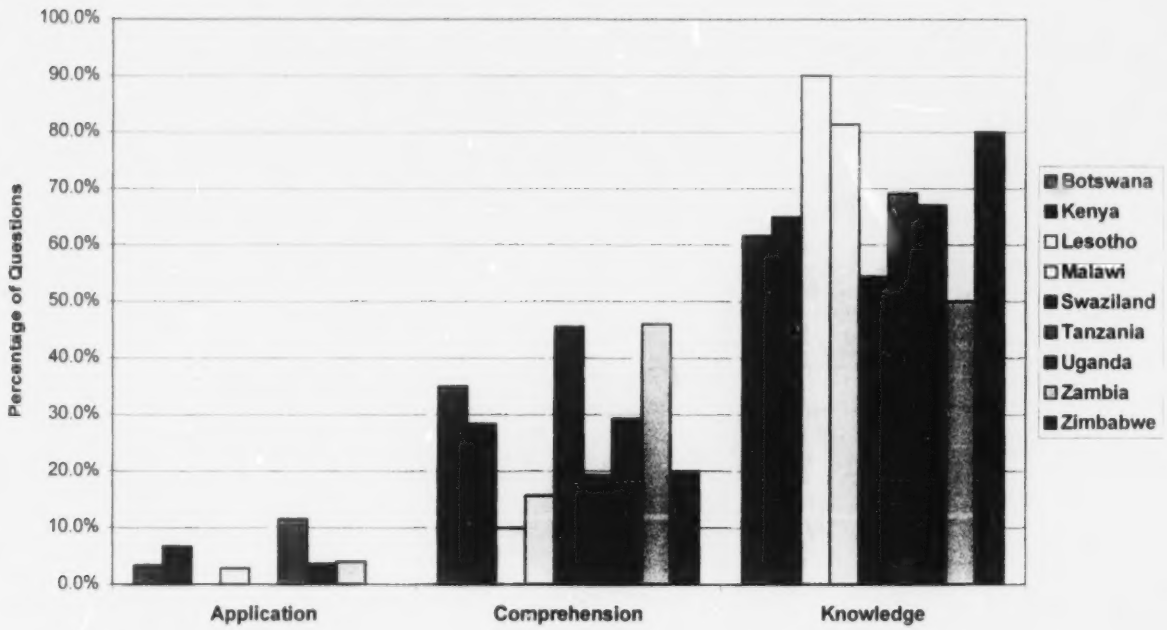
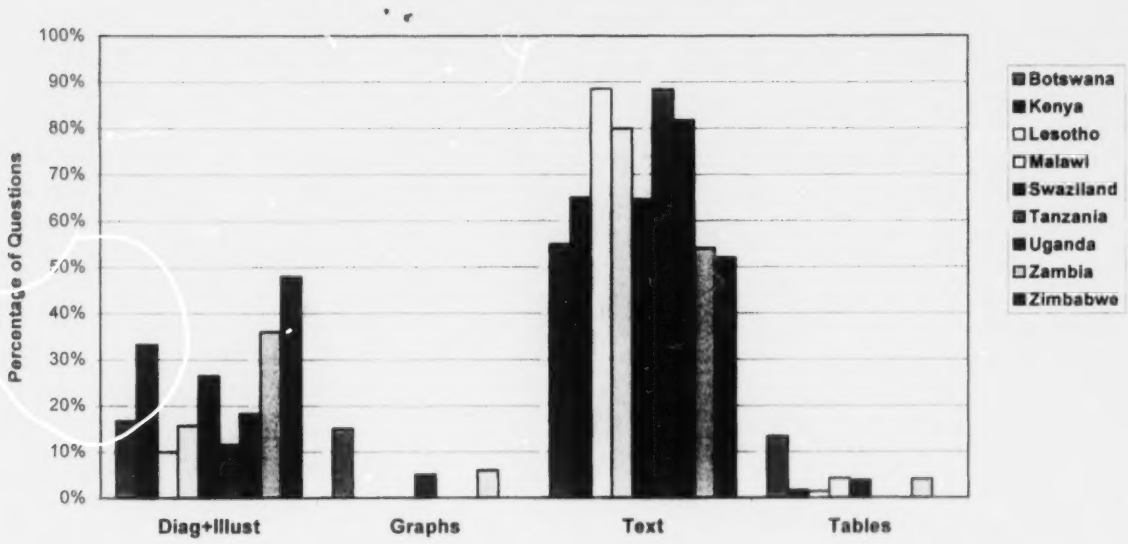


Figure 9. Presentation of Questions - 1997 Papers



Source for Fig 8 and 9: Lewin and Dunne 2000

Two aspects of the curriculum/assessment relationship in science subjects stand out. First, the kinds of outcomes that science curricula often aspire to can only be assessed through a combination of written tasks under examination conditions, performance of practically based activities, and study and reporting activities that may extend over a relatively long time and involve collaborative work with others. Many valued outcomes will not be assessed unless it is possible to introduce some elements of school-based examining. This is relatively uncommon in developing countries. It is likely to have significant costs in terms of time and requires minimum levels of competence in the design and application of assessment techniques by teachers.

The second aspect is concerned with opportunities to reshape the curriculum/assessment relationship through the introduction of curricula based on criteria of competency. At first sight competency-based approaches appear attractive and feasible. In principle the invitation is to define performance outcomes that profile competency at a particular level by specifying statements of mastery within relevant domains. These then provide the criterion behaviours against which students performance can be assessed. The curricula, and certainly the assessment instruments, almost write themselves since the structure and content of items are suggested by domain statements.

What seems a simple and logical approach to redefining the relationship between assessment and curricula turns out to have many difficulties in practice (Lewin 1997). Domain statements in science are not always simple statements that can define competencies very precisely. A risk is that attempts to achieve increased precision results in a very lengthy list of competencies, so long as to lose much practical application. Competency-based approaches to curriculum development may also have difficulty in defining outcomes that are both sufficiently

challenging to test the most able students of a given age, and not too difficult to completely discourage the less able.

Despite these and other difficulties, policy makers and planners have begun to favour competency-based approaches to curriculum and assessment. At the very least they focus attention on attempts to define valued outcomes in measurable ways. They also draw attention to whether or not the full range of curriculum outcomes are assessed, and provide evidence on the extent to which students achieve different levels of competence. The form the assessment takes can be used to encourage the learning outcomes that are valued.

Third, assessing practical work remains problematic because it is expensive and inconvenient to organise. As noted above, there is not much evidence that public examination results are influenced by the amount and quality of practical work undertaken, and assessment of many outcomes thought to be promoted by practical work interacts with more general cognitive competencies. The expense of practical examining arises partly from the need to assess under controlled conditions where all candidates attempt the same tasks at approximately the same time. This requires that standard apparatus and consumables should be available. If specimens of any kind are involved this may add to the problems since large numbers may have to be procured, quality assured, and distribution problems solved. Additional costs will be involved in the setting up time needed to arrange school laboratories for examinations, which often disrupt normal teaching for substantial periods. A further cost arises if any element of performance, as opposed to outcome, is to be assessed, since this can only be undertaken as it happens. Elements of technique, some aspects of observational skills, and design and experimental development skills can only properly be assessed by observing and following the processes a student goes through. Even if this is done using checklists the process will be time consuming.

Five questions can be posed to inform future policy on assessment of practical work:

(i) Does practical examining contribute to the assessment of unique knowledge and skills? This rarely seems the case in practice. Much practical examining is too superficial to tap knowledge and skills that are not accessible to good proxy measurements, which are more convenient and less costly.

(ii) If practical work is not examined, will teachers continue to allocate time to practical work? Practical work is much rarer in practice than is specified in curriculum documents; existing patterns of assessment do not seem to be a determinant of its quantity and quality.

(iii) Is practical examining fair in the sense that all candidates have a reasonably similar preparation for examinations and perform under similar conditions? This is unlikely, since all candidates would have to experience similar levels of exposure to laboratory environments and the opportunities to acquire practical skills.

(iv) Is school based examining of practical activity a suitable substitute for examining practical work under examination conditions? It is almost certainly preferable to assess practical activity through school-based methods than through conventional practical examinations. It requires effective systems of moderation; assessment competencies amongst teachers; and the provision of sufficient time for systematic regimes of school-based assessment to be implemented.

(v) Are there more cost effective ways of assessing practical knowledge and skills? Much of the thinking associated with approaches to experimental problems can be simulated with test instruments that require stimulus material (photographs, diagrams, Figures and graphs) and written answers. It may be possible to test many skills (e.g. observation, collection and processing of data, interpretation of data; experimental design) at least as well as they are currently tested in practical examinations.

Fourth, where national examining systems test students on technically valid and reliable items, large amounts of performance data are generated each year. This can be used to explore a whole range of questions including what differences exist between rural and urban students; what are the kinds of gender based differences in performance; which aspects of the science curriculum are consistently found difficult by different groups of students; and what characteristics are associated with improving and deteriorating performance in science at the school level.

These questions are important, but often the answers to them are unknown and thus cannot be considered in the policy and planning process. Urban /rural differences in performance can be such that there is a standard deviation or more of difference in performance between secondary schools in different locations. Some types of assessment items can discriminate in favour of rural students. Overall performance differences are related to the balance of items of this type. Differences in achievement between groups can have their origins in small parts of the science curriculum rather than in all areas. Thus in some cases much of the variance in performance between boys and girls may originate from physical science in general and electromagnetism in particular. This carries strategic implications for curriculum development and in service support. Paradoxically it is often true that high performing schools have large class sizes as a result of excess demand, and may coexist with low performing schools with small classes. Simple associations between class size and achievement in science can be misleading. School effectiveness methods can be applied to assessment and other data to gain insights into policy interventions that might have more effect than others.

In summary the following conclusions can be reached:

- How science is assessed and what weight is given to science performance in selection examinations is a critical issue for policy and planning. The methods and content of assessment instruments define valued outcomes in assessment-orientated education systems. Changes in the content and the levels of cognitive demand of assessment instruments may be a very cost effective way of influencing learning and teaching. Increasing the weight of science in selection to higher education levels may increase participation and effective demand.
- Outcomes-based and competency-related assessments have attractions for science education. They can help clarify learning objectives, establish the extent to which learning is occurring and competencies are acquired, and contribute to complementary and reinforcing relationships between curricula and assessment. Standards should be set which are achievable by the majority of students in average schools; as performance improves standards should be raised.

- More school-based assessment appears desirable but may not be feasible, unless fairly high levels of professionalisation have been reached amongst teachers and adequate moderating procedures can be employed. Mixed systems, which couple external examinations with internal assessments, can offer the advantages of both - objective assessment, assessment related to actual classroom experience, the testing of a wide range of science learning outcomes - but may have some additional costs.
- Alternatives to external practical examining should be considered. Moderated school-based assessment is attractive, but may not be viable where resources are scarce.
- Opportunities should be taken to analyse assessment data to explore patterns of achievement and factors associated with differences in performance. This needs to be undertaken at a detailed level by technically competent researchers. Crude pass rates are an insufficient guide to science education performance. They cannot generate useful formative feedback or guide policy interventions based on evidence of what makes a difference.

The Training of Science Teachers

Many studies suggest that more qualified and experienced science teachers are associated with higher levels of achievement in science more often than not. Attracting and retaining sufficient numbers of science graduates into the teaching profession remains a serious problem in countries where these graduates are high in demand and are better paid in the private sector in other occupations. It is often suggested that entering the teaching profession is the result of a negative choice by students who have failed to find other employment opportunities. This is likely to be less of a problem where the output of those with science qualifications has been large and there are more applicants than places for teacher training. A surplus of science qualification holders, whether as a result of an over-production of graduates or of a shrinking labour market means that higher quality applicants can be selected than would otherwise be the case.

There are many issues related to science teacher education in developing countries (e.g. Ware 1992). Here three can be discussed. First, what are the characteristics and competencies in science of prospective science teachers and how can these be improved, second how are science teachers trained and does this training prepare them adequately for the conditions under which they will have to teach science, third, how are science teachers deployed and supported in schools and how long are they likely to work as science teachers?

First, the profile of science teachers in different countries varies according to the educational levels/credentials that are required for admission to training. In some developing countries a minimum entry level is defined by secondary school leaving qualification in science, in others a degree may be required. Some countries have admissions tests organised by colleges or universities. Others, which do not have public examinations at the end of secondary, depend on university entrance tests or some other form of assessment. Levels of achievement amongst entrants to teaching are often unimpressive. It is not unusual to find that many science teacher trainees have low grade passes in science at secondary level. Where this is so it carries implications for the nature of training since subject competence is weak.

It is also the case that in a significant number of developing countries entrants into initial training have already had some experience as teachers. Practice varies between countries but often

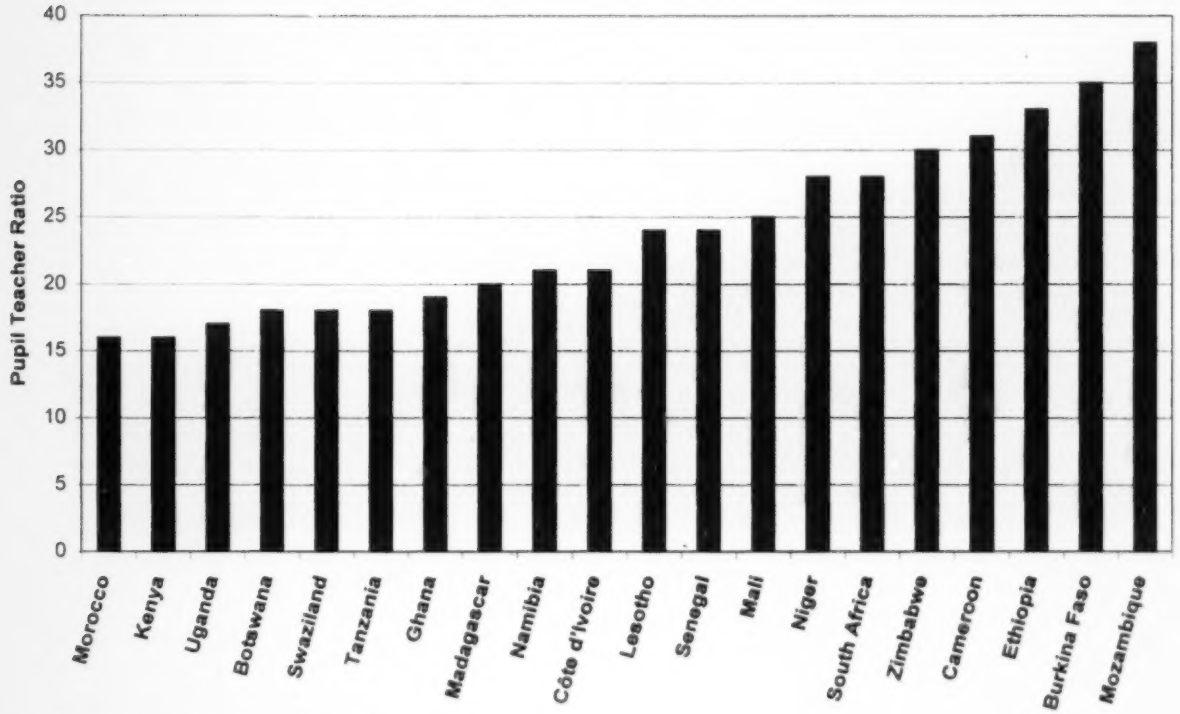
new recruits are drawn from those working as untrained teachers or teaching assistants. In some cases these trainees will have experienced some systematic on-the-job training; in others no provision will have been made. In principle, experience in teaching provides some evidence of the suitability and competence of trainees that can be used to improve selection. In practice, this is rarely done systematically.

Second, initial teacher training programmes vary in length, content and curriculum organisation. The maximum length is about four years, but can be as little as two years post secondary. Where there are sufficient graduates, postgraduate one year training post-first degree is offered. Many countries distinguish between lower and upper secondary teachers and provide different courses for each. Where the supply permits, upper secondary teachers often have graduate status. In some cases this extends to lower secondary teachers.

The major curriculum issues in most training systems are the balance between subject matter upgrading, general education and pedagogic studies, and professional studies including teaching practice. Effective science teaching undoubtedly requires an adequate level of subject matter knowledge. It also requires some theoretical understanding of how students learn and the professional skills associated with managing learning, motivating learners and presenting material in forms that can be understood by students of different ages and capabilities. Decisions on what the balance should be have to consider the subject competence of trainees on entry, the level at which they will teach, the nature of the schools in which they will teach, and the time and other resources available for training. Subject-based time allocations can vary from as little as 30% to as much as 80% of the time available. General education and pedagogic studies may take between 10% and 60% of the time and professional studies between 20% and 40%. Teaching practice in most conventional full time training programmes covers a range between about 12 and 24 weeks.

It is worth noting that the effectiveness of training will be associated with the extent to which training experiences are matched to likely teaching environments. One elaboration makes the point. Pupil/teacher ratios in secondary schools in developing countries cover the range between about 15:1 and 40:1 (Figure 10). This implies class sizes on average of between about 30:1 and 80:1, given that class teacher ratios in secondary schools are often around 2:1 since, unlike in most primary school systems, secondary teachers are generally timetabled with significant amounts of non-teaching time. If trainees are to be prepared to teach classes in excess of say 50 students, training emphasis on small group work and individual experimentation in science may be inappropriate.

Figure 10. Secondary Pupil Teacher Ratios - Africa



Source: UNESCO Statistical Database 1998

Third, the deployment of science teachers is known to be problematic. Distribution is often uneven with surpluses in favoured schools co-existing with shortages in others. It may also be the case that trained science teachers are not teaching science but other subjects or are promoted to administrative posts, thus exacerbating shortages that may exist. Few systems in developing countries have systems that deploy new science teachers in ways that could reinforce the benefits of their training. Two main systems exist. In one teachers are posted to schools by a central authority. More often than not this results in posting to less favoured schools with weak infrastructure and teaching resources since the politics of posting usually favour established teachers who move to more desirable locations. Market systems that allow new teachers to apply for advertised jobs tend to exacerbate shortages in unfavoured locations. Either system could work more efficiently. If posting were rational and based more on need as determined by analysis of school staff and curriculum demand for science, the match between those trained in science and those teaching science should improve. Market systems will only work if there are incentives for trained teachers to apply for jobs where they are needed most. If this is not so, and there is a shortage of supply, there will be concentration in schools in favoured locations.

It is also important to establish the average length of a science teacher's career. Attrition amongst science teachers is typically higher than for other subject specialists. Alternative opportunities are often more readily available for those with science and technology skills. In those countries worst affected by HIV/AIDS attrition is also rising amongst those who are sero-positive.

Attrition rates amongst trained teachers can be anything from minimal to 10% annually or more. In the latter case all those trained will have left the profession within less than 10 years. Clearly the nature of what is considered appropriate and affordable training should be influenced by the level of trained teacher attrition. Where attrition is high it becomes more attractive to consider alternatives to full time pre-career training, which provide several inputs over time integrated with various kinds of school based training and distance support.

Figure 11 provides some food for thought about different patterns of training teachers. Many combinations are possible and cannot be explored in detail here. The main point is that historically inherited patterns of training, most obviously two to four year full time pre-service, may no longer be appropriate to changed conditions. We can note that first, if the competence in science of trainees is low, it may be more cost effective to concentrate on teaching science first to potential teachers to bring them up to a level sufficient to teach with confidence. This is likely to be cheaper to do in upper secondary schools than in training colleges, assuming that schools of sufficient quality exist. It is obvious that adequate levels of science knowledge and skill are a prerequisite for effective teaching. Second, the length of science teachers careers is a critical consideration. If this has been shortening then different patterns of training with lower costs are attractive. Third, although there is much enthusiasm for school-based training in the teacher education literature internationally, this is a pathway with severe limitations in resource poor countries with a high proportion of untrained teachers in schools. It is possible to imagine effective systems based on clusters of schools in which trainees work if there are a sufficient number that can demonstrate good practice. Where this is not the case school-based training will not be attractive. Finally, the kind of training policy that is appropriate has to depend on an assessment of teacher demand. What is possible where the numbers involved are small is very different to circumstances where large numbers need some training over a short period of time. These are questions that can only be answered with reference to broader education policy goals related to how much science should be taught to how many students at what level.

Figure 11. Possible Patterns of Science Teacher Education

Mode	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
	Pre Training		College Training			Post Training
1						
		no experience	Full time training	Full time training	Full time training	
2						
		pre-course programme	Full time training	Full time training	Full time training	post course mentor support
3						
	unsupported	Teaching	Full time training	Full time training	Full time training	
4						
	mentored	Teaching	Full time training	Full time training	Full time training	post course mentor support
5						
	mentored	Teaching	Full time training	In school + INSET	In school + INSET	In school + INSET
6						
	mentored	Teaching	Full time + in school	Full time + in school	Full time + in school	post course mentor support
7						
	mentored	Teaching	School Based INSET	School Based INSET	mentor+distance	mentor+distance

Source: Lewin 1998

Information and Communication Technologies and Science Education

There are several ways in which information and communication technologies can transform the educational landscape (Lewin 2000b). These include allowing access to high quality learning material available from remote sites; facilitating novel learning materials; permitting open connectivity between learners and between learners and teachers independent of location; and managing learning and monitoring progress. In principle teachers can already download a wealth of science instructional material from websites, including that which is interactive. Computers, networked or otherwise, can run software that simulates many standard science experiments, and offers interactive experiences that are otherwise difficult or impossible to provide. The potential for science student to learn from each other at a distance is evident, as are the possibilities for following distance courses. It is also clear that the management of science education could benefit from databases, inventory controls and ordering systems that might, in all or part, be

electronically configured. Record keeping on student progress and the analysis of assessment data to establish learning difficulties can also be more efficient using computer based systems.

In order to have an impact some antecedent conditions are likely to need meeting. Adequate hardware, software and connectivity are all essential if ICT infrastructure is to be sufficient to allow the opportunities identified to be turned into actualities. The three are interdependent. If all elements are not present, many developments cannot take place. Hardware demands imply that interface devices are available at costs and on a scale sufficient to provide frequent access to many users. Technically qualified staff are needed to maintain stand-alone or networked systems. Adequate recurrent funding is necessary to support the cost of upgrading equipment every three to five years. These are significant demands on the resources of school systems.

As important as hardware is the need to identify or develop affordable software appropriate to users' needs, defined in terms of language, application, cultural relevance, and learning needs. It is tempting to assume that the universal aspects of science curricula mean that the chances are that software is already available at a price. This may be true for discrete aspects of the science curriculum (e.g. simulations of common experiments), but it is not true of curricula as a whole, which differ significantly in emphasis and approach between countries. It is also the case that software may require maintenance to keep it configured as intended, and that its effective use benefits from training. Both have costs.

Lastly, but critical to connectivity, reliable connections are needed to the internet. This is problematic where telephone lines are scarce and of low quality and bandwidth. Depending on pricing regimes for telecommunications, it may also be expensive. But without connectivity access to the internet is unavailable, restricting users to stand alone machines or local networks.

It is self-evident that science education can benefit in many ways from access to computers and the internet. These include the opportunities outlined above, many of which apply to other subjects, and some of which are more specific to science (e.g. analysis of data collected with sensors; dynamic simulations of complex natural processes; solutions of equations where human calculations are impractical; and links with science and science teacher education web sites and CD-Rom distribution of learning materials). The potential of ICTs is considerable. Properly managed and supported, and sympathetically integrated into national curricula, they offer a rich set of new opportunities. It can be noted that there is no reason why content for learning systems should not be generated in ways that reflect different national and individual needs by those who acquire the skill and have the motivation. However, the best guess must be that the relative size of markets at a global level is likely to ensure that most applications are produced for rich country consumption and this is likely to continue to influence software and content development related to science education. This may not be optimal, but it is almost inevitable. It will have benefits.

The real difficulties for developing countries are those of costs and infrastructure to sustain reliable access to learners and teachers. Data on telephone access is illuminating. East Asian tiger economies provide telephone access of 50 lines per 100 population or better. In much of Africa line access is below 1 per 100. International telephone calls average over 250 minutes

per person in Hong Kong and Singapore, but less than a minute per year in most of the poorest countries (UNDP 1997, World Bank 1999). Estimates of the number of graduates in science and engineering give some indication of the availability of those who can technically manage and develop ICT systems. This varies from less than 2 per 10,000 inhabitants in some countries in Sub-Saharan Africa to over 100 in some European countries (Caillods, Gottelman Duret and Lewin 1997). Connectivity in the mid 1990s varied enormously. The US had over 6 million internet hosts in 1996, compared to 23,000 in Singapore, 2,400 in Indonesia, 90 in Zimbabwe and 60 in Uganda (Mansell and Wehn 1998). The connection costs for internet access in the poorest countries can be greater than in the richest. Subscriptions to internet service providers are often set at international levels since many of the service providers are directly or indirectly located in rich countries.

The amounts invested in formal education by governments give some indication of the magnitude of recurrent public expenditure available to support ICT related developments in education. If the available data[1] on 54 countries on expenditure per child at primary is analysed in three groups - GNP of more than US$8,000, between US$1,500 and US$8,000, and below US$1,500 - the results are shown in Table 3.

Table 3. Average GNP, GNP per Capita, Public Expenditure per Primary School Child and per Tertiary Student by Country Group

Country Group By Average GNP per capita	Average total GNP (US$ Billions)	Average GNP per capita (US$)	Public educational expenditure per primary child (US$)	Public educational expenditure per tertiary student (US$)
More than US$8000	990	22800	4300	8580
US$1500-$8000	94	3620	390	2260
Less than US$1500	5	450	50	1210

These amounts per child can be translated into estimates of the public recurrent expenditure that might be available to support ICT based innovations in learning. If 90% of recurrent expenditure is in salary costs then 10% of the expenditure per child is available to cover all non-salary spending. In the poorest countries this amounts to about $5 per child per year. In middle income countries an equivalent estimation would yield about $40 per child per year and in the richest group about $430. Not all non-salary expenditure is available to support ICT based innovations. Most will be committed to maintenance, non-ICT learning materials and equipment etc. If perhaps 20% of non-salary allocations could be linked to new developments

[1] UNESCO Statistical Database (UNESCO 1997. Data on educational expenditure at primary level has been chosen to illustrate the point because it is widely available, it is generally the largest element in educational spending, and it is the level at which most children are enrolled. Data on secondary school expenditure is less available and less comparable across countries. So far as can be judged it averages less than twice that for primary in rich countries. In the poorest developing countries it is can be more than five times greater than primary school per capita expenditure, but participation is generally relatively low. (Lewin and Caillods 2000).

related to ICTs this would mean that whatever was provided at school level would have to be delivered for less than $1 per child per year in the poorest countries at primary level (and perhaps $2-$5 at secondary). In rich countries this figure is more like $90. At tertiary level the poorest countries allocate on average about $1,200 per student and the richest $8600. If 20% of this is non-salary spending, and 20% of this is available to support ICT-based systems then this translates into $48 per student in the poorest countries and $350 in the richest. Whatever the threshold is to meet the antecedent conditions necessary for viable and sustainable ICT-based learning systems, it is likely to be much more than $1 per child per year[2], but conceivably less than $48.

This analysis provides clear signals that ICTs that require frequent and individualised access to a wide user group are unlikely to be feasible in the poorest countries in the near future. Small pockets of users can be created that are connected reliably. This may include intermediaries (e.g. teacher educators, in-service co-ordinators, curriculum developers) who can share benefits with the broader community of education professionals. If there is a public strategy it will be one that provides selective access focused by resource constraints and critical areas in which ICT-based systems can have an impact that can be sustained. Science education is one of these, but not at the level of individual mass access. In middle income developing countries, it is feasible to imagine connectivity spreading to substantial parts of the population over the next decade. How far this penetrates formal learning systems will depend on the investment decisions that governments and individuals make.

Concluding Remarks

This map of issues in science education policy and planning is selective. There are many other important issues on which space prevents elaboration. A short list of these includes the following.

First, language policy issues can be very important. Science is often taught through a medium of instruction which is not a mother tongue. Where it is taught in national languages, there is often a transition point to an international language. Many problems of science learning may be associated with lack of language fluency. In some languages resource material for science is very limited.

Second, little has been said about the process of science education, the learning theories that explore how cognition develops, and the implications of these for curricula and teaching methods. A lot is known about how students learn science in different communities, what misconceptions they have, and what errors in reasoning and deductions they make. Much of this

[2] These rough calculations probably underestimate the differences in resources available between rich and poor countries. The prices of ICT-related goods and services are linked to international markets. Computer hardware and connectivity is rarely cheaper and often more expensive and is priced in $ terms. More investment is needed for the same levels of performance and access. The quality and distribution of infrastructure (telephone system, electrification, buildings) is such that creating environments is which ICT can function reliably may also be more, rather than less, expensive and require extensive investment from non-education budgets.

is not grounded in developing countries, but derived from research undertaken elsewhere. It is an issue for science education policy and planning to find ways of supporting research linked to development in different countries, which really does make a difference to the practice of science education. Progress on this has been disappointingly slow.

Third, the impact of new information and communication technologies on science education is uncertain. The opportunities are extensive. They carry with them both considerable potential benefits and some risks. Reliable access to the internet is extremely varied across developing countries. Large quantities of useful and useless information and learning material are available on-line. The development of professional networks of science educators across countries offers exciting possibilities that could help improve science education quality and access. The potential is not the realisation. Careful consideration has to be given to which strategies really do offer benefits at an education system level that match needs at sustainable levels of cost.

Fourth, questions of access, quality and outcome in science education cannot be separated from more general issues that affect education systems. Effective science education is most likely to be found in effective schools. These are in part educational management questions. The desirable state of affairs where schools operate in a regular and accountable way, absenteeism is low, resources are well managed, support and supervisory services operate purposefully, and most teachers are trained and appropriately deployed is often not a reality in many developing countries. Science education is a sub-system that has it own characteristics that can be a separate focus of attention. However it does have to be seen in a more general system context if interventions, which are to have positive effects, are to be identified.

This paper set out to locate science education policy within a general framework related to development priorities and how they are identified. It then outlined some key contextual factors that shape policy and planing and developed perspectives on a number of issues that recur in debates on science education. It has argued that it is important to recognise that science education exists within a cultural, institutional and developmental context that differs between countries. Some secondary school systems are very selective; others are not. Some have separate schools identified and resourced to provide high quality science and technology education, others do not. Science curricula are organised in many different ways with differing levels of subject integration, time allocations, expectations of practical work, and emphasis on the academic or the applied. The extent to which science teachers are trained as specialists within a conventional discipline, or prepared to teach across a range of subjects also varies. All these things constitute starting points for policy and planning.

The last point is that established patterns of providing science education exist for reasons related to previous decisions and accommodations of competing methods of organising schools and curricula. Most developing countries have a substantial history of attempts to extend access, improve curricula and revitalise learning and teaching in science and improve achievement. There is much to learn from this history about why some innovations have taken root and many others have delivered less than they promised. Diagnosis is a starting point for policy. Those involved need to pause long enough to reflect on what has and has not worked before reinventing broken wheels. Curriculum development alone is not a solution to problems of unsatisfactory

learning and teaching methods and low achievement, if these have their causes elsewhere. Neither is investment in facilities and equipment where these cannot be shown to have a direct relationship to improved learning outcomes.

Improved access, participation and achievement in science education should be a priority goal of education policy. The knowledge and skills it can provide are central to the development process and to the satisfaction of individual and community level needs. This paper identifies some ways forward that raise critical questions for policy that can only be answered in context with a view of the needs, constraints and educational realities within each developing country.

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